Chapter 4. GRADING CRITERIA

12. SELECTIVE GRADING.

a. In developing an airport, proper grading is the most important single factor contributing to the success of the drainage system. Grading and drainage plans should be most carefully coordinated. Cross sections for runways and taxiways should be developed with sloping shoulders so that the surface water is directed away from the pavements and into areas for collection and disposal. The life of the pavements and the functions of drainage can generally be improved by selective grading.

b. Before grading activities are started, the engineer should have complete soil test data of the different soils encountered on the site and data on materials from any borrow sources. As determined from the soil profile and the soil characteristics, the best types of available excavated materials should be so selected and placed to form the strongest and most drainable soil structures beneath and adjacent to the pavement. The more undesirable soils should be placed in the intermediate areas as far removed from the pavements as possible.

c. Gradient design standards are found in:

(1) AC 150/5300-2A, Airport Design Standards—Site Requirements for Terminal Navigational Facilities.

(2) AC 150/5300-4A, Utility Airports,

(3) AC 150/5325-2B, Airport Design Standards—Air Carrier Airports—Surface Gradient and Line of Sight.

13. SOIL CONDITIONS.

a. When the soil survey discloses different types and strata of soils on the site, different methods and procedures in the grading and drainage construction should be considered. In grading, fills are made of the material obtained from cuts and other excavation. Therefore, a basis of design is an understanding of the nature of the soils that will be encountered.

(1) On sites where the soils are of a good pervious type and are drainable, the drainage problem is greatly simplified. This type of soil is generally the contributing factor for natural drainage. The major consideration of such a site is to determine whether an impervious strata, which might pocket the water as it percolates downward, underlies the pervious surface soils. If so, provisions must be made to remove the trapped water. Usually, though, the only consideration necessary is proper grading of the area to provide for surface runoff. The slope of the graded areas must be carefully controlled because such soils may tend to erode.

(2) Sites with impervious soils are a different drainage problem. By their nature, very little precipitation will infiltrate into impervious soil. In such cases, there is little need for any subsurface drainage. Surface drainage is required, however, and will have to be designed to take care of the estimated runoff. Some impervious soils are also subject to erosion, and this characteristic should be considered.

Some clay type soils may give the appearance of being impervious, but they actually allow a very high capillary rise from the water table, which can saturate the subbase or base course. In such cases, subsurface drains at the pavement edge will help keep the subbase or base dry.

(3) At sites where pervious soils are superimposed on impervious soils, tests should be made to determine the extent and the profile of the top of the underlying layer. Some surface drainage will be needed and may be provided by proper grading with occasional inlets in the low areas, but some system of sub-

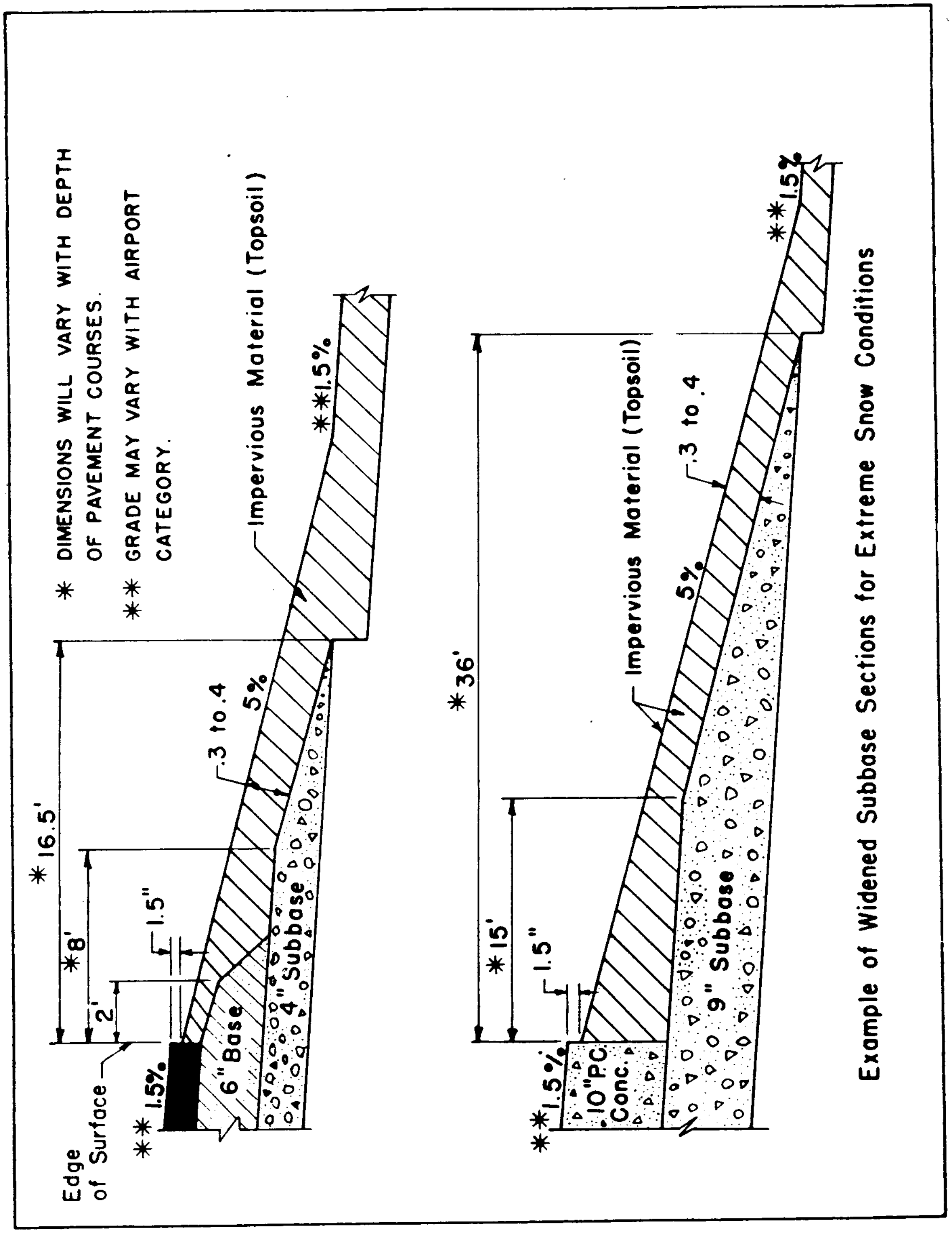

FIGURE 26. Example of widened subbase sections for extreme snow conditions.

drainage is definitely required to remove the water from the top of the impervious layer. If the layer is not too far below the surface, the subdrainage pipe trenches should extend slightly into the impervious layer (approximately 6 inches) and be backfilled with a granular material. The granular backfill material should be placed around and adjacent to the pipe.

(4) There are cases where an airport will be located on a site in which an impervious layer of soil is on the surface, with a pervious stratum below. Surface drainage will always be needed for draining such a site, and the system should be designed to remove all of the estimated runoff. Again, a thorough understanding of the types and extent of the soil with their respective profiles will be needed because grading operations may open up or pocket the underlying porous stratum. The underlying porous stratum often introduces underground water onto a site, requiring intercepting ditches along the edges of the airport or an intercepting drain line to cut off and divert this flow. Surface runoff sometimes may be directed into the porous layer, if it is extensive enough, by tapping through the top impervious layer with proper structures, and allowing the surface water to enter the porous layer.

(5) Drainage engineers frequently find the situation in which there are irregular strata of pervious and impervious materials. The most important thing in this situation is to locate all of the pockets existing beneath the surface and to provide sufficient drains to remove the water from them. Drainage from those pockets can be piped directly from the site or fed into the surface drainage system by proper connections. In some cases it may be necessary to remove the undesirable material from the pockets, especially under and adjacent to the pavement, and to backfill with desirable material.

b. In seasonal frost areas it is important to determine the frost penetration, since the drainage pipelines should be placed below this depth whenever possible. A serious condition could develop if the drainage lines were laid above the frost penertation line. The system could become inoperative when water freezes upon contact with the drainpipes. Field determinations of frost penetration show that the depth of penetration for various soils are fairly consistent for the same location.

(1) In granular soils, frost enters the ground quicker, penetrates deeper at an earlier stage, and leaves the ground more rapidly in the spring than in a tighter clay soil. In a clay soil the frost gradually leaves in the early spring from both the top and the bottom of the frozen stratum. It finally thaws out at a point somewhere near the midsection between the ground surface and the point of deepest penetration. During this thawing-out period, the soil becomes saturated and very unstable.

(2) Frost heaving may also occur and cause damage to the drainage system. Frost heaving is the result of freezing of capillary moisture that cannot be removed by drainage from certain soils of a silty or silty sand texture. The best way to eliminate frost heave is to remove the unfavorable soil to a sufficient depth and to replace it with a suitable material not subject to frost heave. In some localities, low temperatures and snowfalls result in deep frost penertation and deep accumulations of snow on the pavement shoulder areas and adjacent thereto. As a consequence, the thaw period is prolonged and may result in saturation of the subgrade and instability of the base or subbase.

Installation of edge subdrains is the usual solution, however, it may be found that a widened subbase will be as effective and of reasonable cost. The examples of widened subbase sections shown in Figure 26 are not intended to be standard, as the dimensions and some of the grades will vary with the pavement depth and the airport category. This method of subsurface drainage is not advocated for airports unless it has been shown to be practical in the general soil and climatological situation applicable to the site.

14. LOADS ON CONDUITS.

a. In the design and construction of drainage system conduits under pavement, the maximum anticipated wheel loads should re-

TABLE III. Minimum depth of cover in feet for pipe under flexible pavement (Part 1)

CORRUGATED ALUMINUM 2 2/3" x 1/2" or 2" x 1/2" CORRUGATIONS

AIRCRAFT WHEEL LOAD—Up to 30,000 lb. single and up to 40,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.)								
	12	18	24	36	48	60	72	84	96
0.060	2.0	2.5	2.5						
0.075	1.5	2.0	2.5	2.5	3.0				
0.105		1.5	1.5	1.5	2.0	2.5	3.0		
0.135			1.0	1.0	1.5	1.5	1.5		
0.165					1.0	1.5	1.5	2.0	2.0

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.)								
	12	18	24	36	48	60	72	84	96
0.060	2.0	2.5	2.5						
0.075	1.5	2.0	2.5	2.5	3.0				
0.105		1.5	1.5	1.5	2.0	2.5	3.0		
0.135				1.5	1.5	2.0	2.5	3.0	
0.165					1.5	1.5	2.0	2.0	2.5

AIRCRAFT WHEEL LOAD—110,000 lb. dual to 200,000 lb. dual; 190,000 lb. dt. to 350,000 lb. dt; up to 750,000 lb. ddt & 1,500,000 lb

Metal thickness (in.)	Pipe diameter (in.)								
	12	18	24	36	48	60	72	84	96
0.060	3.0	3.0	3.0						
0.075	3.0	3.0	3.0	3.5	5.0				
0.105		2.0	2.0	2.5	3.5	4.5			
0.135				2.0	3.0	4.0	4.5	5.5	
0.165					2.5	3.5	4.0	5.0	5.5

CORRUGATED ALUMINUM 6" x 1" CORRUGATIONS

AIRCRAFT WHEEL LOAD—up to 30,000 lb. single and up to 40,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.)							
	36	48	60	72	84	96	108	120
0.060	2.0	2.0	2.5	3.0				
0.075	1.0	1.5	2.0	2.5	3.5			
0.105	1.0	1.0	1.5	2.0	3.0	3.5		
0.135			1.5	2.0	2.5	3.0	4.0	
0.165					2.0	2.5	3.5	4.5

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.)							
	36	48	60	72	84	96	108	120
0.060	2.5	3.0	3.5	4.0				
0.075	1.5	2.0	2.5	3.0	4.0			
0.105	1.5	1.5	2.0	2.5	3.5	4.0		
0.135			2.0	2.5	3.0	3.5	4.5	
0.165					2.5	3.0	4.0	5.0

AIRCRAFT WHEEL LOAD—110,000 lb. d. to 200,000 lb. d; 190,000 lb. dt. to 350,000 lb. dt.; up to 750,000 lb. ddt. & 1,500,000 lb.

Metal thickness (in.)	Pipe diameter (in.)							
	36	48	60	72	84	96	108	120
0.060	4.0	4.5	5.0	5.0				
0.075	3.0	3.5	3.5	4.0	4.0			
0.105	2.0	2.0	3.0	2.5	4.0	4.5		
0.135			2.5	3.0	3.5	4.0	5.0	
0.165					3.0	3.5	4.5	5.5

CLAY

AIRCRAFT WHEEL LOAD—up to 30,000 lb. single and up to 40,000 lb. dual

Pipe type	Pipe diameter (in.)								
	6	10	12	15	18	21	24	30	36
Std.strength clay	2.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Extra strength clay	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Pipe type	Pipe diameter (in.)								
	6	10	12	15	18	21	24	30	36
Std. strength clay	4.0	5.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Extra strength clay	2.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5

ASBESTOS CEMENT

AIRCRAFT WHEEL LOAD—up to 30,000 lb. single and up to 40,000 lb. dual

Asbestos cement-class	Pipe diameter (in.)								
	6	10	12	16	18	24	30	36	42
1500	2.5	2.5	2.5	2.5					
2400	2.5	2.5	2.5	2.5	2.5	2.5			
3300	1.5	1.5	1.5	1.5	1.5	1.5	1.5		
4000		1.5	1.5	1.5	1.5	1.5	1.5	1.5	
5000		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
6000								1.0	1.0
7000								1.0	1.0

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Asbestos cement-class	Pipe diameter (in.)								
	6	10	12	16	18	24	30	36	42
1500	5.5	5.5	5.5	5.5					
2400	6.0	6.0	6.0	6.0	6.0	6.0			
3300	3.5	3.5	3.5	3.5	3.5	3.5			
4000		3.5	3.5	3.5	3.5	3.5	3.5	3.5	
5000		3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
6000								2.5	2.5
7000								2.5	2.5

TABLE III.—Minimum depth of cover in feet for pipe under flexible pavement (Part 2)

CORRUGATED STEEL 2 2/3″ x 1/2″ CORRUGATIONS

AIRCRAFT WHEEL LOAD—Up to 30,000 lb. single and up to 40,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.) 12	18	24	36	48	60	72	84	96
0.052	1.0	1.0	1.5	1.5					
0.064	1.0	1.0	1.0	1.5	1.5				
0.079	1.0	1.0	1.0	1.5	1.5	1.5			
0.109			1.0	1.0	1.0	1.0	1.5		
0.138				1.0	1.0	1.0	1.0	1.5	
0.168				1.0	1.0	1.0	1.0	1.5	1.5

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.) 12	18	24	36	48	60	72	84	96
0.052	1.5	2.0	2.0	2.5					
0.064	1.5	1.5	2.0	2.5	2.5				
0.079	1.5	1.5	2.0	2.5	2.5	2.5			
0.109			1.5	2.0	2.0	2.0	2.5		
0.138				2.0	2.0	2.0	2.0	2.5	
0.168				2.0	1.5	2.0	2.0	2.0	2.5

AIRCRAFT WHEEL LOAD—110,000 lb. dual to 200,000 lb. dual; 190,000 lb. dt. to 350,000 lb. dt.; up to 750,000 lb. ddt.

Metal thickness (in.)	Pipe diameter (in.) 12	18	24	36	48	60	72	84	96
0.052	2.0	2.5	3.0	3.0					
0.064	2.0	2.5	2.5	3.0	3.0				
0.079	2.0	2.0	2.5	2.5	2.5	3.0			
0.109			2.0	2.5	2.5	2.5	3.0		
0.138				2.0	2.0	2.5	3.0	3.0	
0.168				2.0	2.0	2.5	3.0	3.0	3.0

AIRCRAFT WHEEL LOAD—Up to 1,500,000 lb.

Metal thickness (in.)	Pipe diameter (in.) 12	18	24	36	48	60	72	84	96
0.052	2.5	2.5	3.0	3.0					
0.064	2.5	2.5	2.5	3.0	3.0				
0.079	2.5	2.5	2.5	2.5	2.5	3.0			
0.109			2.5	2.5	2.5	2.5	3.0		
0.138				2.5	2.5	2.5	3.0	3.0	
0.168					2.5	2.5	3.0	3.0	3.0

CORRUGATED STEEL 3″ x 1″ CORRUGATIONS

AIRCRAFT WHEEL LOAD—Up to 30,000 lb. single and up to 40,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.) 36	48	60	72	84	96	108	120
0.052	1.5	2.0	2.0	2.0				
0.064	1.0	1.5	1.5	2.0	2.0	2.0		
0.079	1.0	1.0	1.5	1.5	2.0	2.0	2.0	
0.109	1.0	1.0	1.0	1.0	1.5	1.5	2.0	2.0
0.138	1.0	1.0	1.0	1.0	1.0	1.5	2.0	2.0
0.168	1.0	1.0	1.0	1.0	1.0	1.5	2.0	2.0

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.) 36	48	60	72	84	96	108	120
0.052	2.5	3.0	3.0	3.0				
0.064	2.0	2.5	2.5	3.0	3.0	3.0		
0.079	1.5	2.0	2.5	2.5	3.0	3.0	3.0	
0.109	1.5	1.5	2.0	2.0	2.0	2.5	3.0	3.0
0.138	1.5	1.5	1.5	2.0	2.0	2.0	2.5	2.5
0.168	1.5	1.5	1.5	1.5	2.0	2.0	2.0	2.5

AIRCRAFT WHEEL LOAD—110,000 lb. dual to 200,000 lb. dual; 190,000 lb. dt. to 350,000 lb. dt; up to 750,000 lb. ddt.

Metal thickness (in.)	Pipe diameter (in.) 36	48	60	72	84	96	108	120
0.052	3.0	3.5	3.5					
0.064	2.5	3.0	3.5	3.5	3.5			
0.079	2.0	2.5	3.0	3.0	3.5	3.5		
0.109	2.0	2.0	2.5	2.5	3.0	3.5	3.5	3.5
0.138	2.0	2.0	2.0	2.5	3.0	3.0	3.5	3.5
0.168	2.0	2.0	2.0	2.0	2.5	2.5	3.0	3.0

AIRCRAFT WHEEL LOAD—Up to 1,500,000 lb.

Metal thickness (in.)	Pipe diameter (in.) 36	48	60	72	84	96	108	120
0.052	3.0	3.5	3.5					
0.064	2.5	3.0	3.5	3.5	3.5			
0.079	2.5	2.5	3.0	3.0	3.5	3.5		
0.109	2.5	2.5	2.5	2.5	3.0	3.5	3.5	3.5
0.138	2.5	2.5	2.5	2.5	3.0	3.0	3.5	3.5
0.168	2.5	2.5	2.5	2.5	2.5	2.5	3.0	3.0

STRUCTURAL PLATE PIPE—9″ x 2 1/2″ CORR. FOR ALUMINUM; 6″ x 2″ CORRUGATIONS FOR STEEL

AIRCRAFT WHEEL LOAD—Up to 30,000 lb. s. or 40,000 lb. d.	AIRCRAFT WHEEL LOAD—40,000 lb. d. to 110,000 lb. d.	AIRCRAFT WHEEL LOAD—110 k.d. to 200k.d.; 190 k d.t. to 350 k. d.t.; to 750 k. d.d.t.	AIRCRAFT WHEEL LOAD—Up to 1,500,000 lb.
Pipe dia.÷8 but not less than 1.0′	Pipe dia÷6 but not less than 1.5′	Pipe dia.÷5 but not less than 2.0′	Pipe dia÷4 but not less than 2.5′

TABLE III.—Minimum depth of cover in feet for pipe under flexible pavement (Part 3)

NONREINFORCED CONCRETE

AIRCRAFT WHEEL LOAD—Up to 30,000 lb. single and up to 40,000 lb. dual

Pipe type	Pipe diameter (in.) 4	6	8	10	12	15	18	21	24
Std. strength	2.0	2.0	2.0	2.0	2.5	2.5	2.5	2.5	2.5
Extra strength	1.0	1.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Pipe type	Pipe diameter (in.) 4	6	8	10	12	15	18	21	24
Std. strength	3.5	4.0	4.0	4.5	5.5	6.0	6.0	6.0	6.0
Extra strength	1.5	2.0	2.5	3.0	3.5	3.5	3.5	3.5	3.5

REINFORCED CONCRETE

AIRCRAFT WHEEL LOAD—Up to 30,000 lb. single and up to 40,000 lb. dual

Reinf. concrete 0.01″ crack D-load	Pipe diameter (in.) 12	15	18	21	24	27	30	33	36	42	48	54	60	72	84	96	108	120	132	144
800													1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1000	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1350	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2000	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
3000	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Reinf. concrete 0.01″ crack D-load	Pipe diameter (in.) 12	15	18	21	24	27	30	33	36	42	48	54	60	72	84	96	108	120	132	144
800													6.5	5.5	4.5	3.5	2.0	1.5	1.5	1.0
1000	5.5	5.5	5.5	5.5	5.5	5.0	5.0	5.0	4.5	4.5	4.0	4.0	3.5	3.0	2.0	1.5	1.0	1.0	1.0	1.0
1350	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5	3.0	3.0	2.5	2.0	2.0	1.5	1.0	1.0	1.0	1.0	1.0	1.0
2000	3.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
3000	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

AIRCRAFT WHEEL LOAD—110,000 lb. dual to 200,000 lb. dual; 190,000 lb. dual tandem to 350,000 lb. dual tandem; up to 750,000 lb. d.d.t.

Reinf. concrete 0.01″ crack D-load	Pipe diameter (in.) 12	15	18	21	24	27	30	33	36	42	48	54	60	72	84	96	108	120	132	144
800																				
1000																				
1350	7.0	7.0	7.0	7.0	7.0	6.5	6.5	6.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	5.5	5.5	5.0	4.5	4.0
2000	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5	3.0	2.5	2.0	2.0	2.5	2.5	2.0	2.0	2.0	1.5
3000	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.0	1.0	1.0	1.5	1.5	1.0	1.0	1.0	1.0

AIRCRAFT WHEEL LOAD—Up to 1,500,000 lb.

Reinf. concrete 0.01″ crack D-load	Pipe diameter (in.) 12	15	18	21	24	27	30	33	36	42	48	54	60	72	84	96	108	120	132	144
2000	7.0	7.0	7.0	7.0	7.0	6.5	6.5	6.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
3000	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

1. Cover depths are measured from top of flexible pavement, however, provide at least 1 foot between bottom of pavement structure and top of pipe.
2. The types of pipe shown are available in intermediate sizes, such as 6″, 8″, 15″, 27″, 33″, etc.
3. For pipe installation in turfed areas use cover depths shown for 30,000 pound single; 40,000 pound dual.
4. Cover depths shown do not provide for freezing conditions. Usually the pipe invert should be below maximum frost penetration.
5. Blanks in tables indicate that pipe will not meet strength requirements.
6. Minimum cover depths shown for flexible pipe are based on use of excellent backfill.
7. Minimum cover depths shown for rigid pipe are based on use of class B bedding.
8. Minimum cover requirements for concrete arch or elliptical pipe may be taken from tables for reinforced concrete circular pipe, providing the outside horizontal span of the arch or elliptical pipe is matched to outside diameter of the circular pipe (assumes that classes of the pipes are the same).
9. Pipe cover requirements for "up to 1,500,000 pounds" are theoretical as gear configuration is not known.

RIGID PAVEMENT

For all types and sizes of pipe use 1.5 foot as minimum cover under rigid pavement (measure from bottom of slab, providing pipe is kept below subbase course). Rigid pipe for loads categorized as "up to 1,500,000 lb." must, however, be either class IV or class V reinforced concrete.

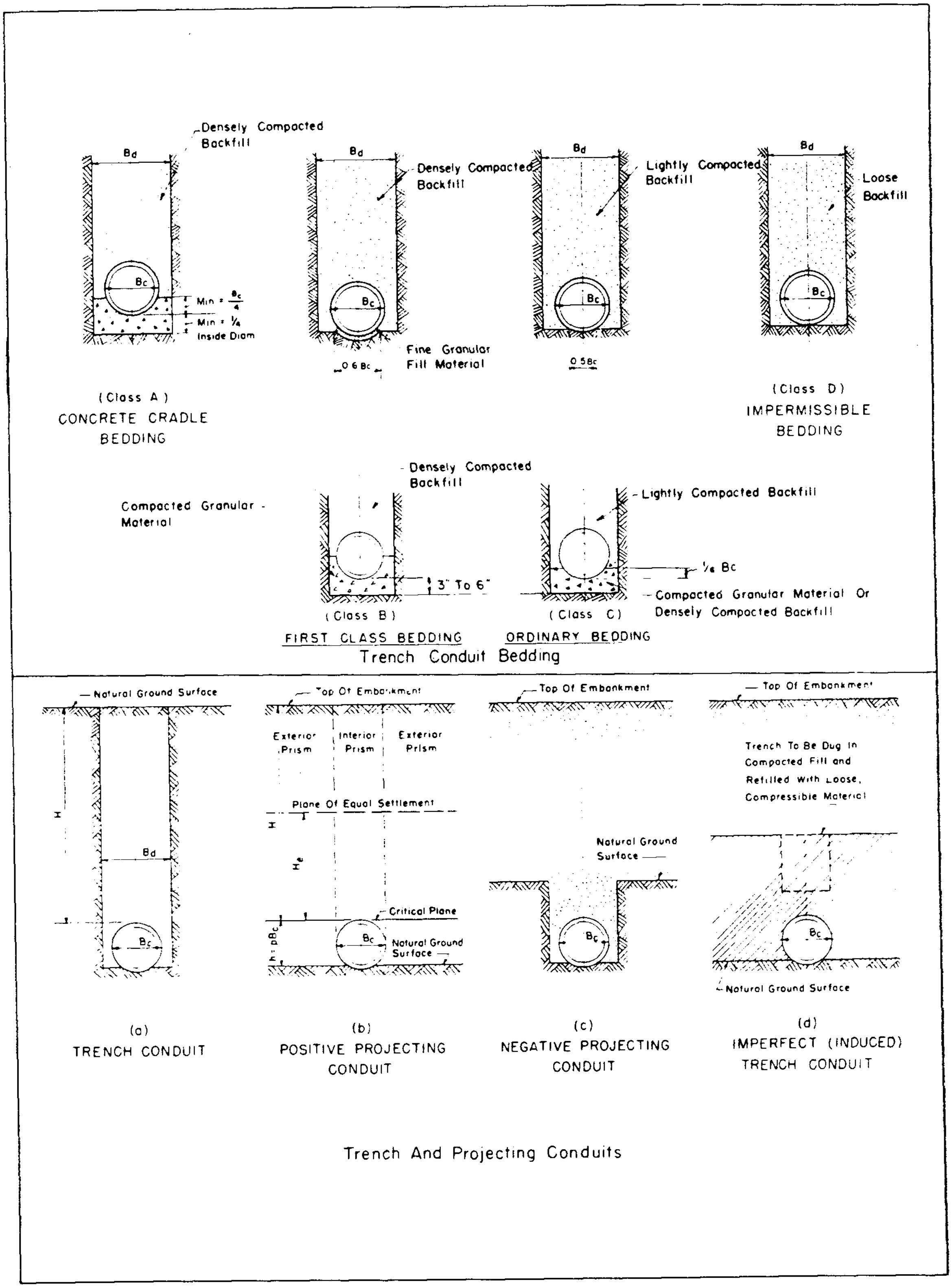

FIGURE 27. Trench and projecting conduits.

ceive consideration. The pipe grades should be established to provide the necessary depth of cover, that is, the distance between the top of the pipe and the pavement. A safe design requires consideration of the probable maximum wheel load, the inherent strength of the pipe, the details of construction conditions, the type and bearing strength of the pavement, and a factor of safety. The design of airport pavements is predicated on gross aircraft weights as applied to the type of landing gear geometry, i.e., single, dual, and dual-tandem wheels. The recommended minimum depths of cover given in Table III should be used. Note that cover under flexible pavement varies with the aircraft wheel load and type of pipe, whereas cover under rigid pavement does not involve such variables (see rigid pavement requirements in Table III (Part 3)).

b. The manufacturers of rigid and flexible pipe use different factors and procedures for calculation of loads on pipe. Table III includes recommendations of the manufacturers' organizations for minimum cover requiremets. This publication does not include recommendations for other than minimum cover situations—for other than minimum covers it is suggested that the literature listed in the bibliography be used. That literature permits determination of either the maximum allowable fill height or of pipe types suitabe for depths beyond the influence of live loads. The control and method of placing pipe under high embankments affect the magnitude of the resultant load. When the pipe is installed in a trench of specified width, the resultant load on the conduit is less severe or critical. When the installation does not involve a trench or where the trench width is not controlled—that is, very wide in proportion to width of pipe—the magnitude of the load becomes more critical. Because of the influence of the above installation conditions, underground conduits of the rigid type are classified into two major groups: trench conduits (Figure 27(a)) and embankment conduits (Figure 27(b), (c), and (d)). Embankment conduits are further subddivided into positive and negative projecting subgroups, depending on whether the conduits, as installed, are above or below the existing ground surface.

(1) Trench conduits are those which are installed in relatively narrow trenches dug in passive or undisturbed soil and then covered with earth backfill which extends to the original ground surface or for some distance above the pipe. When the conduit is placed in a trench not wider than two times its outside width and covered with earth, the backfill will tend to settle downward. This downward movement of the backfill in the trench above the conduit is retarded by frictional forces along the sides of the trench which act upward and help support the backfill and thus reduce the dead load.

(2) Computation of actual loads on pipe installed as shown in Figure 27(b)—positive projecting conduit with the pipe placed on the natural ground elevation—shows that the results are very similar to those for pipe installed in trenches (measured at top of conduit), wider than several times the maximum outside conduit width. For both these situations, the load on the conduit could be as much as three times greater than the load on a pipe installed in a narrow trench.

(3) Between these extremes are many variations. The closer the engineer can come to producing a trench type of installation, the more favorable are the loading conditions. There are two methods of construction that would tend to reduce some of the load factors normally found in projection conduits. These are the negative projecting conduits and the imperfect or induced trench, (see Figure 27(c) and (d)).

(a) The negative projecting conduits are those installed in shallow trenches of such depth that the top of the conduit is below the natural ground surface. They are then covered with an embankment which extends some distance above the ground elevation.

(b) The imperfect trench (induced trench) is the method of construction in which a cushion of compressible material is placed in a purposely constructed trench directly above the pipe in the interior of the embankment.

These two installations act to relieve the load on the conduit. Many designers have adopted them for placing conduits under high embankment with remarkable success.

c. The supporting strength of a rigid conduit depends mainly on the width and quality of the contact between the pipe and the bedding, as this affects the distribution of the vertical reaction. Subsidence of conduits is a reflection of the load bearing capacity of the in-place soil and distribution of the load—such capacity should be determined by soil tests. Four classes of bedding are used for installing rigid conduits. They are listed in the order of their relative load distribution capability (see Figure 27).

(1) *Class A:* This method consists of placing the lower part of the conduit in a cradle of concrete having a minimum thickness under the pipe of one-fourth the nominal internal diameter and extending up the sides of the pipe to a height equal to at least one-fourth the outside diameter. The minimum compressive strength of such concrete shall be 200 p.s.i.

(2) *Class B:* This method provides that the conduit be set on fine granular material in an earth foundation carefully shaped to fit the lower part of the pipe exterior for a width of at least 60 percent of the outside diameter of the pipe. Alternatively, the pipe may be bedded in compacted granular material which extends up to the midpoint of the pipe diameter. The remainder of the pipe is entirely surrounded by thoroughly compacted granular materials.

(3) *Class C:* This method requires that the earth foundation be shaped to fit the lower part of the pipe exterior with reasonable closeness for at least 50 percent of the outside diameter of the pipe. Alternatively, the pipe may be bedded in compacted granular material or densely compacted backfill. The remainder of the pipe should be surrounded by compacted granular or fine-grained material.

(4) *Class D:* This method requires little or no care either in shaping the foundation surface to fit the lower part of the pipe exterior or in filling and compacting all spaces under and around the pipe. This method is not recommended.

Experimental data indicate that the four classes of bedding, in the order listed above, have load factors of approximately 2.8, 1.9, 1.5, and 1.1. The load factor is the ratio of the supporting strength of rigid pipe in the field to the strength in the three-edge bearing test (D-load).

d. The term "D-load" is used to express the allowable load on reinforced concrete pipe in pounds per linear foot per foot of internal diameter. Thus, field loads expressed in pounds per linear foot may be converted to D-load by dividing by the nominal pipe diameter in feet. The advantage of the D-load designation is that all sizes of different types and classes of pipe of a given D-load in similar bedding and installation conditions generally will support the same earth load.

e. Conduits installed at a depth somewhat greater than the minimum cover depths of Table III are subjected only to dead loads. The dead loads may be greater or less than the actual weight of the column of material above the conduit, however, the weight of the material is a primary factor in the maximum allowable depth of backfill. The associations representing producers of different types of pipe have prepared tables of allowable depths of backfill for the various sizes, strengths, and shapes of pipe. These tables also take into account such factors as the unit weight of backfill material, width of trench, class of bedding, whether in trench or embankment and for flexible pipe—the stiffness of the pipe wall. The tables are applicable to airport drainage design.

15. LOADS ON STRUCTURES.

a. At some airports it is necessary to install box culverts in lieu of conduits, in order to provide great drainage capacity. Although not related to drainage, utility tunnels are often similar in design to box culverts. These structures, as well as inlet grates and taxiway bridges, are subject to direct aircraft loadings at some airports. Large aircraft such as the B-747, DC-10, L-1011, etc., will impose loads substantially in excess of 350,000 pounds, i.e., up to 860,000 pounds. It is said that increasingly heavy aircraft will be developed so that a 1.5-million pound aircraft appears feasible and reasonably certain to materialize.

Obviously, point loading on some structures will be greatly increased over that used for design assumptions in the recent past. Accordingly, it is recommended that structures, which may need to accept loads such as mentioned here, be designed to withstand the following loadings:

(1) For spans of 2 feet or less in the least direction, a uniform live load of 250 p.s.i.

(2) For spans between 2 feet and 10 feet in the least direction, a uniform live load varying between 50 p.s.i. and 250 p.s.i., in direct proportion to the span length.

(3) For spans of 10 feet or greater in the least direction, the design should be based on the most critical loading condition which may be applied by gear configurations as illustrated in Appendix 2 to AC 150/5320-6A, Airport Paving.

b. The following elements of Appendix 2 to AC 150/5320-6A are also applicable to drainage:

(1) As always, footing design will vary with depth and soil type. For shallow structures or those subject to direct heavy aircraft loads, such as inlets and box culverts, concentrated load design may require heavier and more widely spread footings than heretofore provided.

(2) Locked wheel braking loads must be anticipated for structures subject to direct wheel loads.

(3) Because soil is relatively insensitive to increased loadings, a soil cover is recommended over structures where clearances permit.

16. EROSION CONTROL.

a. An important item in airport drainage is to provide for adequate protection of cut-and-fill slopes. Unless the slopes are correctly designed for the type of material contained in them, erosion will start during the first storm. The usual engineering practice is to establish a certain percentage of slope for the type of material encountered as shown on the soil profile and to maintain that slope throughout the particular section.

b. When cut-and-fill slopes are constructed to obtain the most economical section, some provision for their protection should be made. In airport construction, these slopes are usually made as flat as possible and vary from a 2:1 slope to one as flat as 10:1. Cut slopes more than 8 to 10 feet deep, with higher ground above them, should be provided with a cutoff surface ditch constructed several feet back from the top of the bank and running parallel to the top-of-cut line to intercept the surface water flowing down from the higher ground. To protect the cut slopes, it may be necessary to riprap, sod, sprig, or seed with rapid-growing grass or vegetation. It is good practice also to construct a ditch at the base of the bank to intercept the flow of runoff. Figure 28 illustrates several recommended types of interceptor ditches.

c. All fill-slopes that are more than 5 feet high should be protected against surface water erosion by building berms and gutters along the top of the slope to intercept the surface water and to prevent it from spilling down the slope. The surface water, thus intercepted, may be disposed of by properly constructed concrete spillways, vertical drop inlets, or other suitable means of conducting the water down the slope to proper outfall ditches. Several recommended types of embankment protection structures are shown in Figure 29. When a berm is placed along the top edge of the embankment, some method of protection is necesary, for example, by shooting the berm with a light asphaltic material, sodding the berm, or providing paved gutters. The method which most nearly satisfies local conditions should be used.

d. One oversight in the construction of the spillways has been the failure to provide an adequate cutoff wall beneath the apron at the entrance to the spillway. This cutoff is most important to prevent water from seeping under and along the spillway, and causing faiure from lack of support. It is desirable to construct either a series of baffies or a stilling basin at the base of the spillway to reduce the velocity of the flowing water. The elevation at the outlet should be the same as that of the ditch into which it empties. Where opentrough type spillways are constructed, their cross-sectional area should be larger than that required for the design storm, and provision should be made in the design for ample freeboard.

e. The channel below culvert outlets or spillways should be protected against erosion. Usually headwall or stilling basin structures are provided as illustrated in Figure 29—together with stone riprap in the channel. If a headwall, stilling basin, or riprap is not provided—then erosion may be expected in most soil conditions and with other than minimum velocities. The erosion will occur as gully scour or as a scour hole. Gully scour may erode the bottom and sides of the channel so severely as to undermine the culvert, destroy or clog the channel, and cause loss of embankment. A scour hole can undermine the storm drain causing loss of some of the pipe sections. The required dimensions of the apron of the structure and/or riprap are predictable. For example, hydraulic laboratory investigation and field observations show that gully scour may be expected in a cohesionless soil if the Froude number of flow in the channel below a culvert outlet (without a structure or riprap) is 0.35 or greater. The Froude number (Fo) equals average velocity of flow at the culvert, f.p.s. ($\overline{V}o$) divided by the square root or acceleration due to gravity, ft./sec.^{2} (g) multiplied by the culvert diameter, ft. (Do) or $Fo = \overline{V}o\sqrt{g\ Do}$. Then the length of area to be protected, if maximum tailwater applies, equals Do (8 + 55 Log Fo). The beginning width of such area equals 3 Do and the area increases in width with a flare of 1 on 5. These and other relationships are explained in reference 33 of the bibliography and texts on drainage.

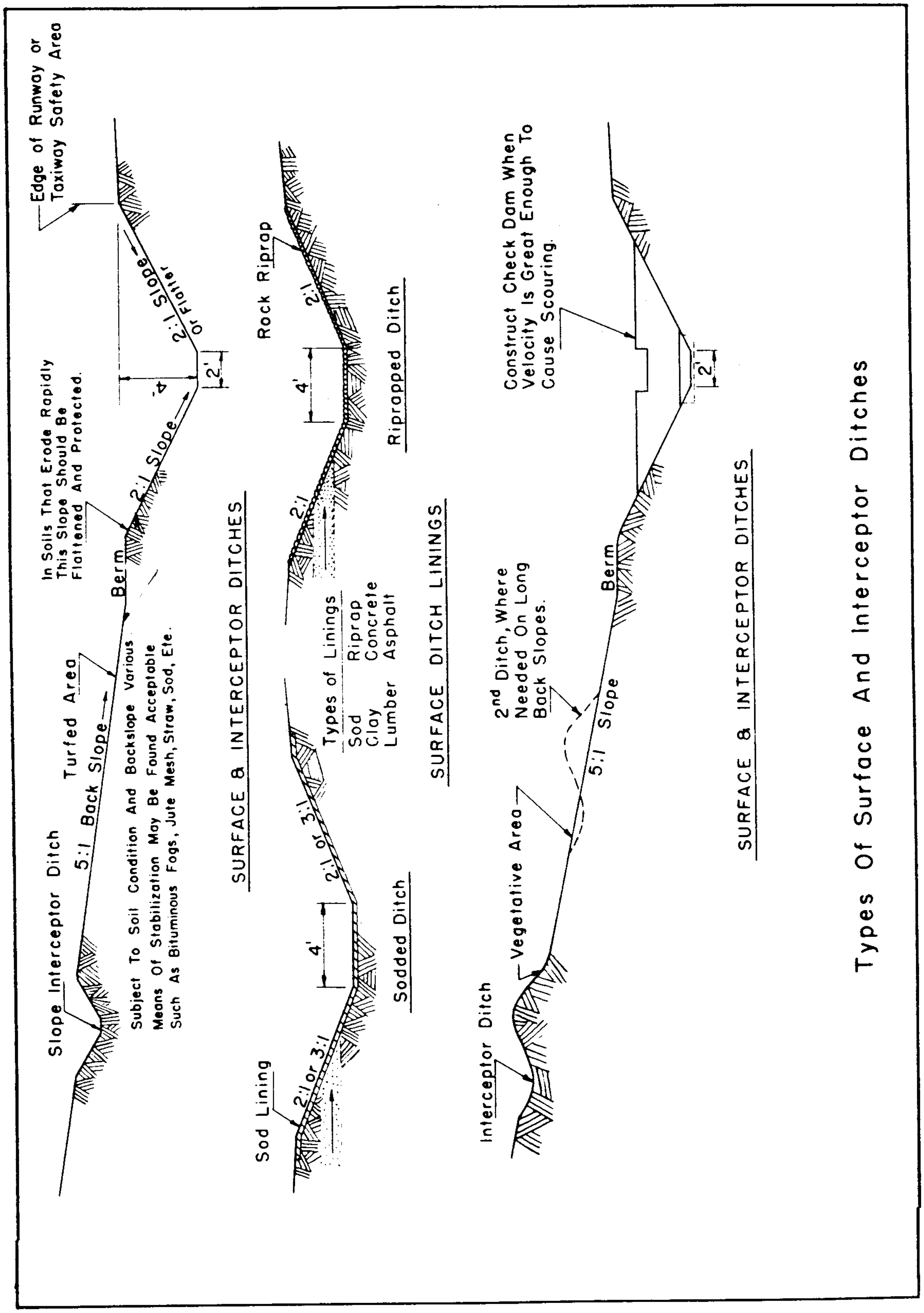

FIGURE 28. Types of surface and interceptor ditches.

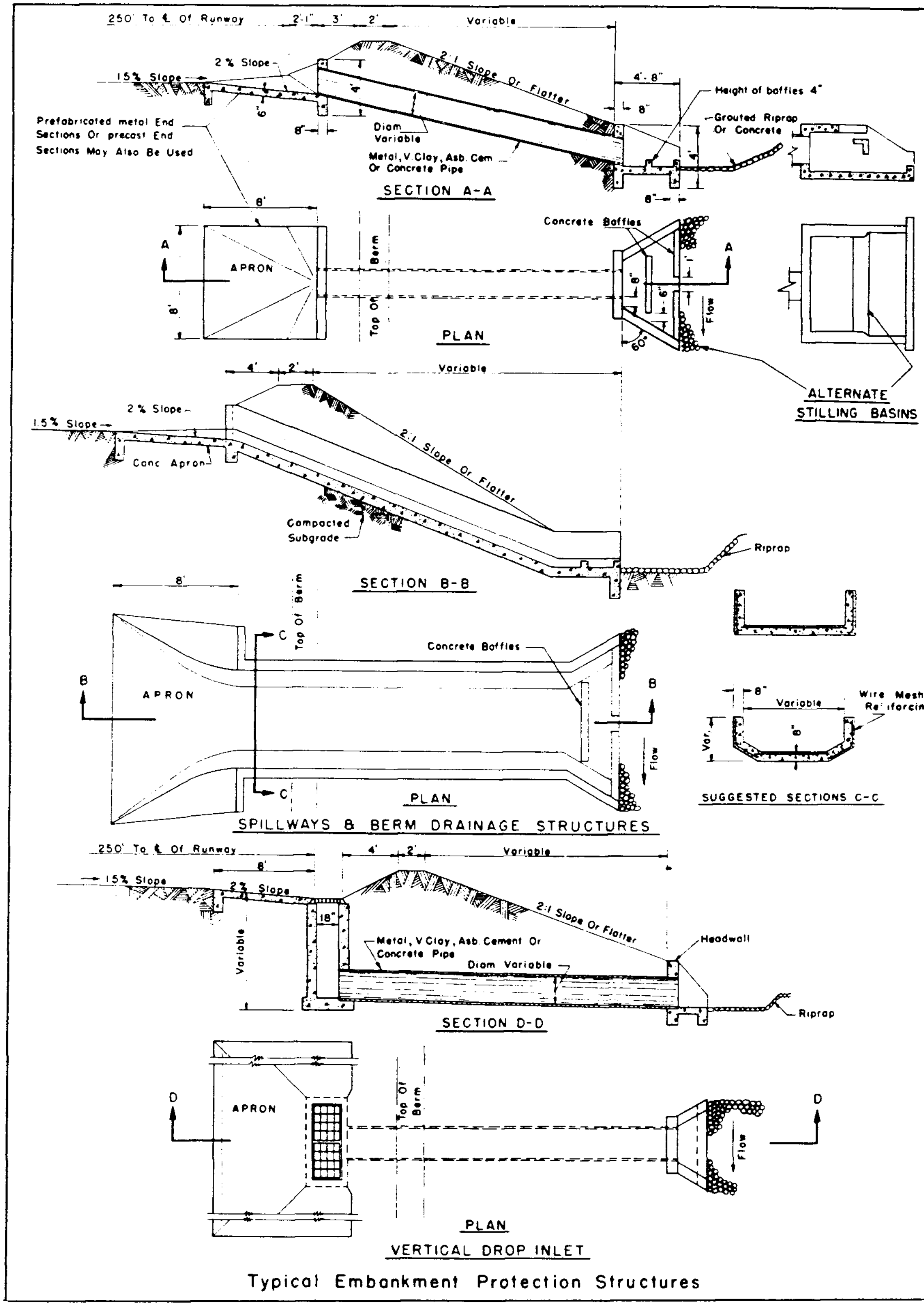

FIGURE 29. Typical embankment protection structures.

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